

# Decision Making under Uncertainty: Climatic Variability, Stakeholders, and Modeling in the Colorado River Basin

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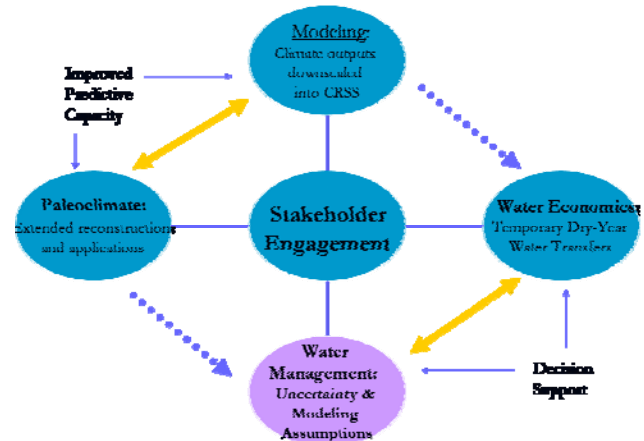
This presentation focuses on growing set of management challenges in the Colorado River basin to address the tightening connection between climatic variability and water supply. In particular, this presentation will emphasizing the role of river system modeling in stakeholder-driven planning processes. This is an applied, interdisciplinary research project.



## Research Overview

- Project Scope & Research Question
- Decision Making Context
- Stakeholder Engagement
- Modeling and Uncertainty in CR long range planning
- Arizona Stakeholder Recommendations
- Conclusions

The figure on the right shows this effort within its interdisciplinary context. This four-pronged effort is funded by the Bureau of Reclamation as well as the Univ of Az Water Sustainability Project. Efforts are made to incorporate tree ring information and downscaled general circulation model outputs into the Bureau's rivers operations modeling. This component of the project focuses on harnessing improvements in predictive capacity into decision support tools needed to interpret model outputs. An economics component is evaluating options for mitigating impacts of climate variability through temporary and voluntary dry year water transfers.



### Decision Making Context: Climatic Variability & Growth in the CR Basin

- Institutionalized Over-allocation
- Shortage as the norm  
(Christensen et al 2004)
- Intensifying reliance on CRSS
- Expanding Stakeholder / Modeling Interface

Given the CR's over-allocation based on an anomalously high streamflow prior to the 1922 compact, the need to confront prolonged system shortage has been anticipated since at least the 1950s megadrought. The probability of shortage was forecast as long ago as 1968 when long

range operating criteria were devised for management of Lakes Powell and Mead. The river is managed according to an annual operating plan which can follow any of three system states: normal, shortage, and surplus. Until 2001, long range criteria only existed for 'normal' conditions; in cases of shortage or surplus, the secretary of interior - the colorado's river master - would determine deviations from normal conditions. With shortage expected to be a systemic, prolonged, and recurring feature of the River system in the future, criteria are now being devised to deal with shortage in a way that avoids making it a yearly contest to influence the Secretary's decision.

Studies, such as Christensen and the Rocky Mountain Climate Organization have also underscored the challenge of managing water supply in the context of climate change. Additionally, tree ring reconstructions of stream flow may not yet offer conclusive evidence that streamflow averages are below those recorded during the instrumental period -- however, droughts of greater severity and duration have appeared in the tree ring reconstructions. Moreover, average is clearly not the ideal measure of central tendency for the river's inflow - since inflow has varied from 4.5 maf to 24 maf in any given water year

### Stakeholder-Driven Research Agenda

- What are the key modeling assumptions and sources of uncertainty in the Colorado River Simulation System (CRSS)? What are the **long-term planning** implications of these assumptions?
- How can model outputs be tailored to aid decision making under uncertainty?

As CRSS has become more accessible, user groups have become more interested in what drives the model, including determining and evaluating the major assumptions and sources of uncertainty in the model. As the second question suggests, understanding the assumptions themselves is necessary but insufficient for guiding long range planning decisions. It is also important to understand the interaction of assumptions and the criteria for comparing alternative operations decisions.

This research focus responds to the priorities articulated by stakeholder groups during an interactive stakeholder engagement process that involved formal discussions with individuals and groups as well as observation during public processes and planning meetings. On the right is a list of stakeholders.

#### Who are the stakeholders?

##### *Direct*

State DWR  
Central Arizona Project  
Salt River Project  
Municipal Water User Groups

##### *Indirect*

On-River Users  
Irrigation Districts  
Power Providers  
Conservation Groups

### Stakeholder / Modeling Nexus Colorado River Simulation System

Here demonstrates the growth of CRSS in stakeholder driven decision making contexts. CRSS: Represents the Colorado River Basin in terms of a system of reservoirs and reaches between reservoirs where a suite of 50 operating policy based rules and over 120 functions to depict physical processes, depletion and other dimensions of the river system.

A key evolution in the stakeholder / modeling interface occurred in the mid-90s when CRSS migrated from a hard-wire fortran-encoded model to an object oriented, graphical interface implemented in a commercial software package called RiverWare. As noted, this brought simulation capacity and analysis to a wider audience of water managers and operators.

It's important to note that other simplifying models have been used to assess the reliability of water supplies under prolonged drought and climate change impacts.

It has become an increasingly integral component of long range planning.

## Data & Research Approach

- Ongoing Stakeholder Engagement
- Two Basin-wide planning processes
  1. Surplus (1996 - 2001)
  2. Shortage (2004 -?)
  3. AZ Shortage Sharing
- CRSS modeling assumptions and outputs:
  - f (inflow, depletion, physical process, operating criteria)
  1. Inflow: Index Sequential Method
  2. Depletion: Upper Basin
  3. Operating Criteria: Surplus Guidelines & 602 (a) criteria
  4. Initial Reservoir Conditions

Two public processes that deal with climatic variability and water supply coupled with growing demand.

The Interim Surplus Guidelines (ISG) model outputs did not project actual observed reservoir declines until 2005 within the range of possible outcomes. The perspective of hindsight is a valuable lens to apply to the Surplus process now that the Basin states are conducting a formal Environmental Impact Statement (EIS) for shortage criteria.

CRSS model outputs are function of a closed river system that combines inflow, depletion, etc. This analysis is buttressed by stakeholder feedback on what measures aid interpretation of modeling results.

## Modeling Assumptions *Inflow: Index Sequential Method (ISM)*

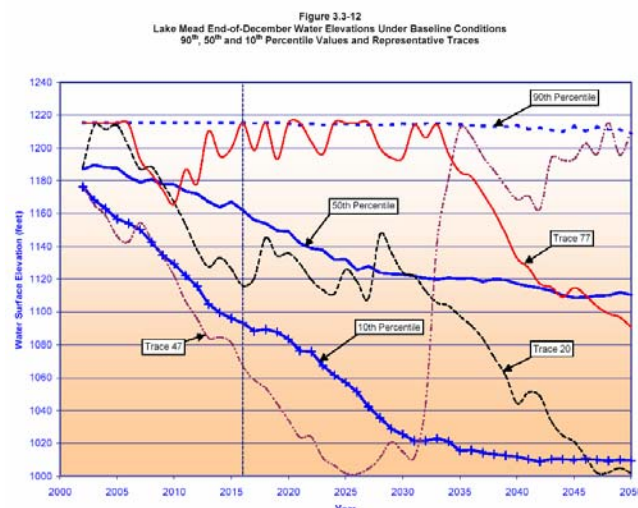
Historical Record: 1906 to 2003\*

Implication: future flows will vary within the range of variability experienced during the historical record; 1999-2004 was novel

Move to the core assumptions. The foundational element is that the past instrumental record of streamflow governs the range of variability introduced into CRSS as the inflows. Historical natural flow inflow data measured at monthly time steps produced a sequential trace starting in each year of the historical record which was just expanded from 1906-1995 to 1906 to 2003, which includes the driest inflow year on record of 2002. At each monthly time step all of the traces are ranked and analyzed according to percentiles.

Bottom line: If it isn't in the past, it may not be represented. Bureau is working to replace ISM with stochastic and/or ensemble streamflow forecasts in the 3 to 5 year timeframe.

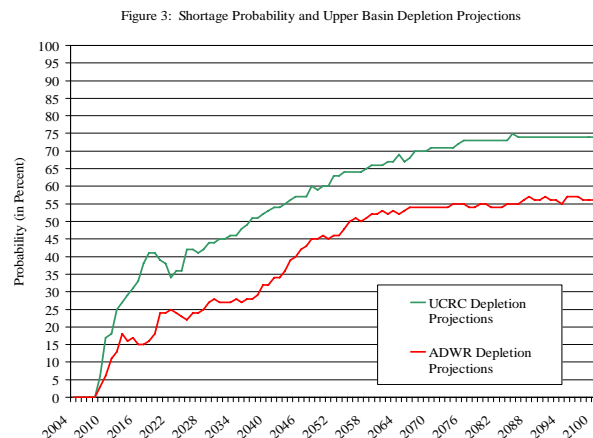
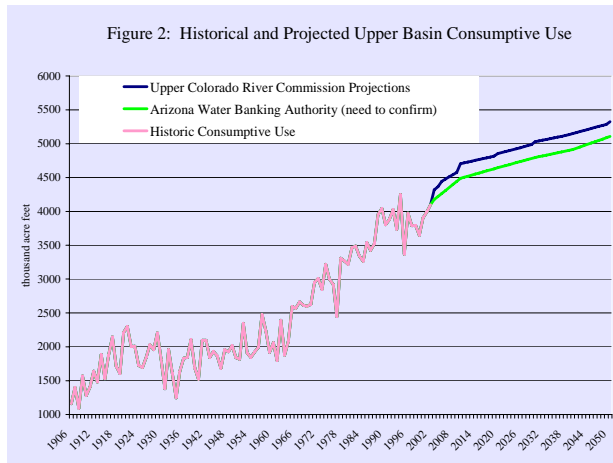
The chart on the right is taken from the Surplus EIS and shows how the monthly values are analyzed to form traces for the major percentile values used by Bureau and state water managers. As you might



Source: Department of Interior, 2001

be able to tell, this chart tracks Lake Mead reservoir levels under baseline surplus criteria - identifying the impact of the variations of inflow. A trace for the 90th percentile, 50th percentile, and 10th percentile values is used as the maximum probable, most probable and minimum probable inflow traces. For many purposes the most probable trace influences decision making, but by using percentiles and median values as the decision criteria, extreme values, such as the recent dry-year spell can be overlooked. In addition to the percentiles are uses, such as trace 47, which starts at the beginning of the 1950s drought, and you can perceive the 83,84 wet year refill in the late spike in that trace.

## Modeling Assumptions *Demand: Upper Basin Depletion*



### *Lower Basin & Upper Basin differ in projections of growth rate; limit*

Another salient assumption is on Upper Basin Depletion, where lower basin and upper basin states diverge in their projection of overall UB depletion as well as the rate of growth. Since the UB has not achieved full allocation, this has a major impact on probability of shortage in the lower basin. Sensitivity analysis of that factor is demonstrated in the graph on the right where the Upper basin's projections of faster growth and higher overall use lead to larger probabilistic of shortage.

## Operational Assumptions: 602 (a) Storage

Operational assumptions are also critically important influences on simulated reservoir conditions. A complex operating criterion - called the 602 (a) storage - determines the amount the Upper Basin must store in Lake Powell to meet Lower basin delivery obligations and it also stipulates conditions for excess releases from Lake Powell to balance with Lake Mead. This assumption has been at the center of discussions over shortage in the Basin. Without getting into the detail here, it is worth noting that this criterion embeds criteria related to climatic variability by ensuring enough storage is available to buffer against the critical inflow period derived from the mega-drought from 1953 to 1964.

## Initial Conditions: *The three- to five-year blinders*

Now that many of the important assumptions for long-term planning have been identified, it's necessary to realize that due to the CR's large reservoir capacity, initial reservoir conditions are determinant over the 3- to 5-year planning timeframe.

### The Worst-Case: *Aligning Assumptions*

To really bound uncertainty to guide long-term planning, it is necessary to align assumptions as tabulated on the right.

#### Arizona Stakeholder Recommendations (2005)

- ✓ Articulate and document the assumptions in model runs
- ✓ Isolate the drivers of variability through sensitivity analyses and consistent constants
- ✓ Establish bounds on uncertainty by defining best and worst case scenarios
- ✓ Evaluate river system in terms of water user impacts instead of reservoir levels or other indirect measures
- ✓ Distinguish between sources of uncertainty over different time scales
- ✓ Foster trust, patience to deal with stakeholder groups with diverse levels of understanding and experience

<i>Combining Assumptions to Form Best- and Worst-Case Scenarios</i>		
<i>Key Assumptions</i>	<i>Shortage Probability</i>	
	<i>HIGHER</i>	<i>LOWER</i>
<i>Inflow</i>	<i>Prolonged drought (e.g. 1999-2004)</i>	<i>Extended high flows (e.g. 1983-1986)</i>
<i>Demand – UB</i>	<i>Limit: 5.4 maf Rate: UCRC</i>	<i>Limit: 4.8 maf Rate: AWBA</i>
<i>Operating Policy: Surplus Criteria</i>	<i>Interim Surplus Guidelines</i>	<i>70R Strategy</i>
<i>Initial Conditions</i>	<i>Jan. 2005 (i.e. 50% capacity)</i>	<i>Jan. 2000 (i.e. nearly full)</i>

#### Decision Making under Uncertainty *Colorado River Shortage*

- Shortage EIS using CRSS lite to compare alternatives
- Coordinated management of Lakes Powell and Mead
- Resolution at different scales
- Augment water supplies
- Flexibility; Interim Accord
- Key: Operational Uncertainty and Legal Framework constrain Basin adaptation

